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COGNITIVE ABILITY AND WHOLE-BODY ROTATION

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SUMMARY

A series of studies examining how whole-body rotation affects cognitive processing is summarized, and a new experiment is described. The main question was whether rotations of the body capture attention and reduce cognitive processing capacity. An additional question was whether the attention caught is resource specific, that is, whether particular cognitive capacities are more affected than others. Previous experiments revealed that cognitive processing comes to a complete standstill while body rotations are made actively on a swivel chair. The duration of the suspension depended on the nature of the cognitive task, suggesting resource specificity. In the present experiment a rotating chair was used on which subjects were rotated while performing on spatial and nonspatial tasks. Performance losses were small and limited to the spatial task. The conclusion based on the whole series of experiments is that body rotations capture general as well as specific processing capacity, but that the amount of capacity caught is small, or the duration of capacity capture is short. Large attention capture is expected only if subjects execute the rotations actively. The striking similarity with the effects of eye movements on cognitive processing suggests that the active search for new information in the visual environment is the real reason why whole-body rotation can be so disturbing.

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Cognitief vermogen en rotatie van het lichaam

L.C. Boer

SAMENVATTING

Een reeks experimenten over de effecten van "whole-body rotation" op de cognitieve taakprestatie wordt samengevat en een nieuw experiment wordt beschreven. De vraag is of lichaamsrotaties de aandacht trekken en afbreuk doen aan de cognitieve capaciteit. Ook werd nagegaan of een bepaald soort aandacht getrokken wordt, en of dus bepaalde cognitieve taken meer nadeel ondervinden dan andere, de zgn. resource specificiteit. Eerdere experimenten lieten zien dat op een bureaustoel gemaakte lichaamsrotaties de cognitieve verwerking hinderden, ja zelfs totaal blokkeerden. De duur van de blokkade hing af van de soort van cognitieve taak, hetgeen een zekere mate van resource specificiteit suggereert. Het huidige experiment maakte gebruik van de gemotoriseerde draaistoel van het IZF. Terwijl gedraaid werd voerden de proefpersonen een ruimtelijke en een niet-ruimtelijke taak uit. Het prestatieverlies was gering en bleef beperkt tot de ruimtelijke taak. Gezien de resultaten van eerdere experimenten is de conclusie dat lichaamsrotaties slechts in geringe mate de aandacht trekken. Forse effecten zijn alleen te verwachten als mensen zelf, dus actief, lichaamsrotaties uitvoeren. De treffende overeenkomst met resultaten inzake cognitieve verwerking en oogbewegingen doet vermoeden dat het actief zoeken naar informatie in het visuele veld de werkelijke oorzaak is dat lichaamsrotaties zo hinderlijk kunnen zijn.

1 GENERAL PROBLEM AREA

Theories on human intelligence assume a differentiation of cognitive abilities, and make distinctions among verbal, spatial, and numerical abilities. The main field of application is test psychology and personnel selection. The generally accepted notion is that there is a differentiation between various cognitive abilities. This implies that it makes sense to assess people's abilities separately and to map this information to the ability requirement profiles corresponding to a particular job.

Similar distinctions are also found in theories of human information processing. These distinctions are less refined and are mainly limited to the distinction between verbal and spatial processing capacity (Wickens, 1984). The field of application is human factors. The idea is that the human operator has problems with combinations of tasks demanding the same processing resources, and that a good design principle is to combine tasks only if they demand different processing resources. This idea can also be used as a guideline for the design of human-machine systems and for the allocation of tasks to operators.

The question of the present series of studies is whether rotation of the body capture cognitive abilities or mental resources, and can, therefore, reduce the amount of processing resources available for other tasks. The more specific question is whether rotation of the body captures spatial resources. Turning the body brings the observer into a different spatial orientation relative to the environment. We easily maintain our spatial orientation after a body turn. Direct perception of the environment is a great help, but even if we turn with eyes closed we do not necessarily lose our orientation. There is apparently a brain mechanism that serves to update our spatial orientation, even in the absence of direct perception. This "dead reckoning" could demand processing capacity.

To address the question, a series of experiments was done in which subjects did a cognitive task while making, or undergoing, whole-body rotation at the same time. A summary of the previous experiments is presented. Thereafter, a new experiment is reported. This experiment serves to complete the factorial design of the larger series of experiments.

2 TASKS AND MOVEMENTS

There is some evidence supporting the idea that movement captures attention. Corballis and McLaren (1982) induced illusory rotation of the stimulus field. They let subjects fixate on a rotating disk before presentation of the stimulus letter. As an aftereffect of seeing the rotation, the letter seemed to be subject to a backward rotation. The task was to judge whether the letter presented was a mirror image or a normal version. Letters were presented in various departures

from the upright position. The assumption is that subjects use mental rotation; they rotate the letter "in the mind" (Cooper & Shepard, 1973a,b; Finke & Shepard, 1986). In the case of Corballis and McLaren, the illusory rotation could go into the same direction as the shortest route for the mental rotation or into the opposite direction. Letters tilted close to the upside-down orientation seemed to be rotated through a suboptimal route as if the suggestion of the illusory aftereffect was accepted. Corballis and McLaren concluded (1982, p.223) "the main influence of the aftereffect is on the subject's decision as to which way to mentally rotate the letter". This is a clear case of what Navon (1984, 1985) has termed outcome conflict or what Fracker and Wickens call confusion between tasks (1989) which is basically a non-resource related notion. The effect must be specific to rotation tasks; it is difficult to image how the direction of the illusory rotation could affect performance in a nonspatial task. It is an open question whether whole-body rotation would have other (stronger?) effects.

Anderson and Stern (1989) induced the sensation of whole-body rotations by using a circular vection drum. The rotations were, hence, illusory. Seated in the drum, subjects did a spatial or a verbal task. For the spatial task, the error rate increased if the drum was moving; for the nonspatial task, the error rate was constant whether the drum was moving or stationary. In a second study, reaction time in another spatial task was increased if the drum was moving. No effects were observed if a verbal task was used (Anderson, personal communication, March 1990).

All studies reviewed used illusory movements. By contrast, in the present experiment real whole-body movements were used with separate tasks to address spatial and verbal-numerical abilities or resources. The test for spatial orientation required subjects to imagine a fixed environment, a geographical map. Stimuli commanded the subjects to imagine a change of observation position, and hence, a change in perspective. The process subjects use doing this will be called mental rotation (see also Boer, 1991). After the mental rotation, subjects had to "point to" a particular location in the imaginary environment. This served as a check on the accuracy of the mental rotation.

The test for verbal-numerical ability required subjects to count in the alphabet (see Logan, 1988). After presentation of an initial letter, specifying the starting position (e.g., "C") a signed addend was presented (e.g., "+2"). Subjects counted the designated number of steps forward or backward (C+2=E; E-2=C).

Subjects did either ability test while making or undergoing physical rotation of the body. All body rotations occurred in the horizontal plane and brought the subjects in a new orientation. Body rotation started upon presentation of the stimulus of the ability test but conveyed no information whatever on the solution to the ability test items and could, hence, be ignored completely. Whether or not subjects involuntarily attended them was the empirical question.

The conditions of body rotation were *active* and *passive*. Subjects in the active body-rotation condition were seated on a swivel chair and turned themselves over a particular angular distance as commanded by body rotation requests presented on a computer display. Subjects in the passive body-rotation task were seated on a motorized chair and were turned around.

One difference of active versus passive body rotation is the necessity for conscious attention. Active body rotations constitute a task for the subjects. Passive body rotations are a pure distracter. They may, however, involuntarily capture attention (*cf.* the immediate arousal due loud noises or tactile stimuli, Sanders, 1983).

A complicating factor for passive body rotations is the vestibular-ocular reflex (VOR) triggered by stimulation of the vestibulum. The VOR consists of a fast saccadic eye movement (as if shifting gaze towards a new object appearing in the periphery) alternating with a slower movement in the opposite direction (as if continuing fixation during the body rotation). VORs are adaptive under normal circumstances because they help the eyes to stabilize the retinal image. However, in the peculiar situation that objects such as computer displays and response panels rotate with the subject, VORs are disruptive because they compromise the stability of the retinal image.

Exact predictions on incidence and strength of the VOR are not easy. VORs are a direct linear function of the amount of rotary acceleration but are at the same moment a complicated function of the visual environment. For example, conscious fixation on an object moving with the body (say, a computer display) may completely suppress the VOR (Guedry, Benson, & Moore, 1982). Other things being equal, however, the prediction is a more potent VOR with increasing rotary accelerations and slower responding because of perceptual problems. This should be observed irrespective of the type of cognitive ability tested.

For active body rotations, VOR-tendencies are adaptive and no VOR-related performance losses are expected.

3 PREVIOUS RESULTS FOR ACTIVE BODY ROTATION

The results for active body rotation can be summarized as follows: Subjects take more time solving test items while turning the body. Fig. 1 illustrates the result. The delay in processing is roughly as long as the duration of the body rotation, and the delay is a function of the duration of the body rotation only—not of any parameter of the ability test. This result was observed in three separate experiments and seems firmly established. The conclusion is that body rotations executed actively capture processing resources and that subjects stop cognitive processing while executing body rotations.

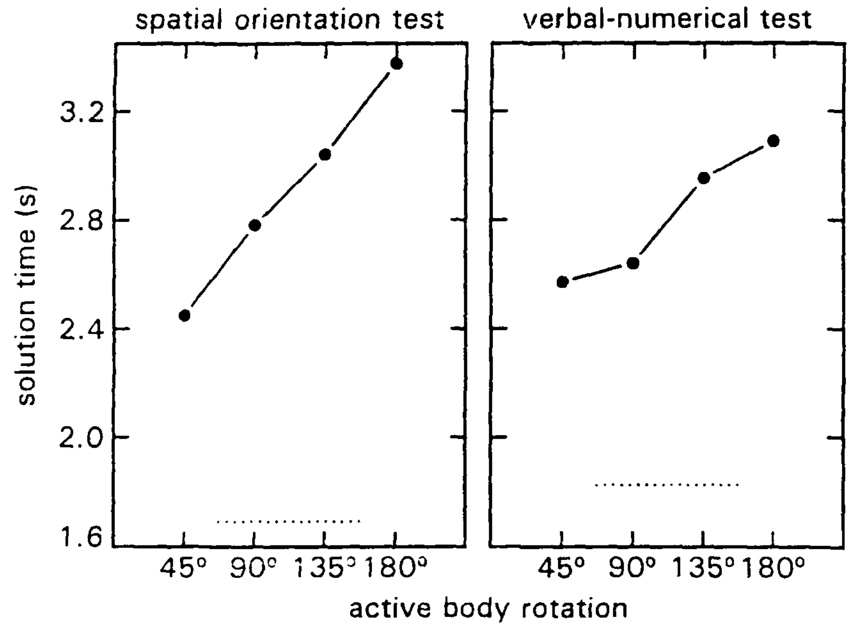

Fig. 1 Time to solve test items as a function of the amount of body rotation made actively on a swivel chair. Dotted lines indicate the control conditions.

In the first experiments, subjects were tested on one ability only: spatial orientation. In the last experiment, shown in the figure, subjects were tested on spatial orientation ability and verbal-numerical ability. The results were the same. The conclusion was that executing body rotations causes a suspension of cognitive processing, irrespective of content of cognitive processing (spatial or verbal-numerical). The interaction between body rotations and cognitive content was, however, significant; the interference due to active body rotations was stronger for the spatial orientation test. This suggests resource specificity; spatial processing is suspended for longer periods of time than verbal-numerical processing.

An exception to the rule that active body rotations suspend cognitive processing was observed in an experiment in which body rotations and mental rotations were perfectly correlated. That is, subjects had to imagine a mental rotation *and* to execute a body rotation with the two rotations having the same direction and the same angle. The objects of the imaginary environment could really have been there, hidden behind the walls of the experimental room. Processing was parallel under these circumstances; subjects continued the cognitive task during the body rotations. The possibility of *integrating* mental and body rotation seems the key to this result. This is another indication of resource specificity; integration between body rotation and cognitive processing is not possible for a nonspatial task.

Suspension of processing was reported also in the visual field studies of Sanders (Sanders & Houtmans, 1984, 1985). In these experiments, subjects inspect two stimuli one after the other, basing their response on the combined stimulus information. The stimuli are wide apart and eye movements take approximately 0.2 s. In this situation, processing was suspended as long as the subjects moved the eyes. Subsequent studies confirmed this result although reporting that cognitive processing was not *always* hampered during eye movements (Boer & Van de Weijgert, 1988). The similarity in results is paralleled by a similarity in the experimental situation. In both the body rotation and the visual field studies, the task requires an active turning of the line of sight toward a new location in space.

4 PREVIOUS RESULTS FOR PASSIVE BODY ROTATION

A different pattern of results emerges for body rotations undergone passively. The chair makes the turn, and there is no need to pay attention to the process of turning. Therefore, less effect on cognitive processing is anticipated. Indeed, a pilot experiment did not reveal any effect of passive body rotations (Boer, 1989, Experiment 1). Apparently, body rotations were ignored and the rotary accelerations did not trigger vestibular eye reflexes. But the experiment had shortcomings such as the presentation of small body rotations (59° at most) and six subjects only. A subsequent experiment presented body rotations between 45 and 180° with maximum rotary acceleration 2.21 rad/s^2 and used two different groups of 20 subjects each for stationary and body-rotation conditions. This time, passive body rotations had three effects: (a) The subject group performing under body rotations did worse than the subject group performing under stationary conditions, (b) the performance loss of the body-rotation group increased with increasing angle of body rotation (see Fig. 2) and, again within the body-rotation group, (c) a performance loss was observed if the body turned in a direction opposite to the direction of the mental rotation. The finding of directional conflict is important, because it suggests that passive body rotations are treated as if conveying information on the spatial orientation test. The effects of directional conflict were, however, small and statistically questionable.

An explanation in terms of the vestibular-ocular reflex is unlikely because the maximum rotary acceleration actually *decreased* with increasing angle of body rotation (2.21 to 0.79 rad/s^2 for body rotations 45° to 180°, respectively). The reason was a purely technical one. The chair could deliver the power for rotary acceleration for a limited period of time only; the power needed for wide angles of body rotation had, hence, to be distributed over longer time intervals. Performance losses due to the VOR should thus be more pronounced for small angles of body rotation. The data showed the opposite.

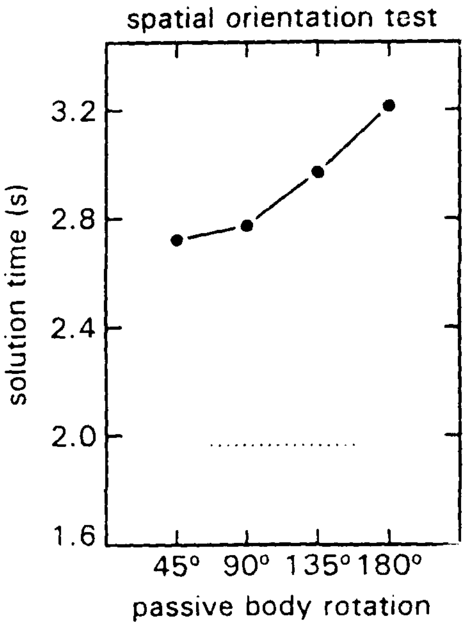

Fig. 2 Time to solve test items as a function of the amount of body rotation undergone passively in a rotating chair. The function (solid line) and the control condition (dotted line) are based on the data of different groups of subjects.

There were no further interactions between passive body rotations and the cognitive test. Generally speaking therefore, passive body rotations seem to add a constant to the time needed to find the solution to the test items, and this constant is a function of the amount of rotation only. The rate of mental rotation was, however, not affected by passive body rotation. It is, therefore, possible that there was a risk of outcome conflict rather than resource competition, and that subjects managed the conflict risk by temporarily freezing their cognitive processing.

5 THE NEXT EXPERIMENT

The experiments discussed thus far comprise a design consisting of a factorial combination of body rotation (active versus passive) and cognitive ability (spatial versus verbal-numerical). The reader will notice that not all combinations have been exhausted. The aim of the present experiment was to complete the design. In particular, the effect of passive body rotations on verbal-numerical ability was investigated. From the experiment on the effect of passive body rotation on spatial orientation, it was concluded that passive body rotation added a constant to the time needed for cognitive processing. However, it cannot yet be said

whether this is a specific or a general effect because the subjects were tested on one ability only. If specific, the effect should be limited to spatial processing, leaving other resources unimpaired. If general, the effect should pertain to all resources, irrespective of their type. The question is thus whether the effect of passive body rotation pertains to spatial tests only, or to other cognitive tests as well.

In the experiment to be reported, subjects were tested on spatial orientation and verbal-numerical ability. Both tests were administered with passive body rotation. Stationary conditions were used as a reference.

A secondary aim of the present experiment was to replicate the earlier result that spatial orientation processing was slower under conditions of passive body rotation. The experiment had some weak points. One was the use of a between-subjects design. The difference between the two conditions could, hence, be due to different ability levels of the two groups. Secondly, the two groups were tested on different apparatus: a desk-top computer for the stationary group and the equipment of a hospital for the passive body-rotation group. The difference between the two conditions could, hence, also be due to the different level of perceived psychological threat.

The present experiment used a within-subjects design in which each subject performed on spatial and verbal-numerical ability tests, under stationary as well as passive body-rotation conditions. The same apparatus was used in all conditions.

Also, an improvement was made in the spatial orientation task. The spatial orientation task requires subjects to imagine mental rotations. They signalled the completion of the process by pressing a "ready" button. A request to "point to" a particular location in the imaginary environment was used to check the accuracy of their mental rotation (see Fig. 5). It was assumed that the mental rotation was correct if subjects made an adequate pointing response. A *direct* check on mental rotation was, however, not available. In the present experiment, the ready button was replaced by eight buttons carrying the names of the various locations of the imaginary environment. Subjects were required to indicate the new location in front of them by pressing one of these buttons.

Expectations

Based on the previous results, the following findings are expected:

(a) Cognitive ability will be somewhat degraded under conditions of passive body rotation. The reference are the stationary conditions. This could be due to specific or nonspecific resource competition or to outcome conflict.

(b) In the experimental condition—passive body rotation—the performance losses will be more pronounced as the angle of body rotation is increased (resource competition or outcome conflict).
(c) In the experimental condition, the performance losses will be increased further if the direction of the body rotation is in conflict with the direction of the mental rotation (outcome conflict).

6 EXPERIMENT

6.1 Subjects

Thirty-eight students participated as paid volunteers. Their mean age was 23.6 years with a range of 20.1 to 39.7 years. They participated under written informed consent. They knew they would be subjected to body rotation and were asked explicitly to report immediately any symptom of motion sickness. They had the right to quit the experiment any time without negative personal consequences.

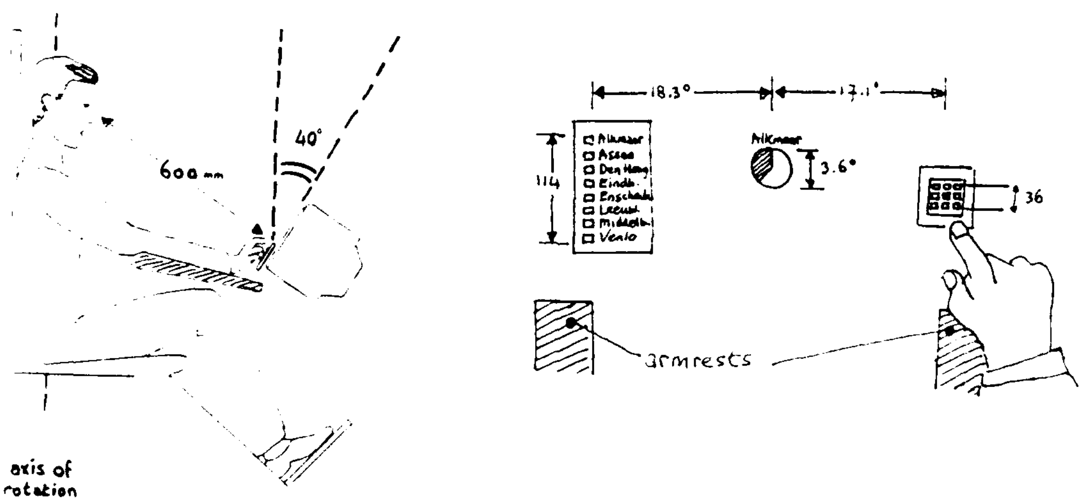

Fig. 3 The experimental apparatus. Left panel: the subject in the rotating chair looking at the display that was attached to the chair. Right panel: the stimulus (spatial task) and the two response panels from the subject's viewpoint. (Measures in mm, unless otherwise indicated.)

6.2 Apparatus and body rotations

A computer display was mounted on a rotating bucket-chair at a distance of 550 to 650 mm from the subjects' eye. Response panels were attached left and right to the display, slightly above the chair's armrests (see Fig. 3). The left-hand

panel contained a row of eight buttons, labelled with the landmarks of the spatial orientation task arranged in the order of the alphabet. The right-hand panel had nine buttons, arranged in a 3 × 3 matrix. The stimuli for either test appeared on the screen between the two response panels. The chair rotated over 45°, 90°, 135°, and 180°, clockwise or counterclockwise. All chair rotations were made in 2.185 seconds. The maximal acceleration was 1.03, 2.07, 3.10, and 4.13 rad/s^2 for the four turns, respectively.

6.3 Spatial orientation test

Subjects imagined themselves in the centre of the Netherlands, surrounded by eight cities marking the compass points North, North-East, East, South-East, South, South-West, West, and North-West. At the start of the trial, an initial orientation of the map was specified by presenting a city name above a circle. Subjects had to imagine themselves facing that city. Four and a half seconds later, a mental-rotation command was presented. To annunciate the command stimulus for mental rotation, the circle began to blink 1 s before its presentation. The command stimulus filled the circle. As illustrated in Fig. 4, it specified a rotation of the imaginary line of sight over 0°, 45°, 90°, 135°, or 180° in either direction.

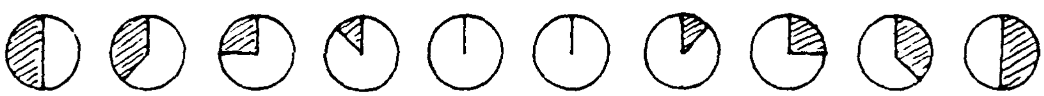

Fig. 4 The stimuli for mental rotations of, in order, -180°, -135°, -90°, -45°, -0°, 0°, 45°, 90°, 135°, and 180°.

Subjects indicated the new city they were facing by selecting a button on the left-hand response panel. The trial was aborted with an error message if the selection was incorrect. If correct, the trial continued with the immediate presentation of a city name preceded by the text "point to". The subjects had to indicate the direction of the city relative to their own imaginary line of sight. The buttons of the 3 × 3 response panel under the right hand were used for pointing. The central button represented the subjects' position (and was never used); the peripheral buttons indicated the various directions relative to the subjects; for example, the button directly above the central button indicated the forward direction (= the current line of sight); the button left from the central button indicated the left-hand direction; &c. The next trial started 0.25 s after the pointing response or, if an error was made, 1.0 s later because an error message was displayed.

Fig. 5 illustrates that the pointing direction is the product of the location of the city specified and the subject's current orientation.

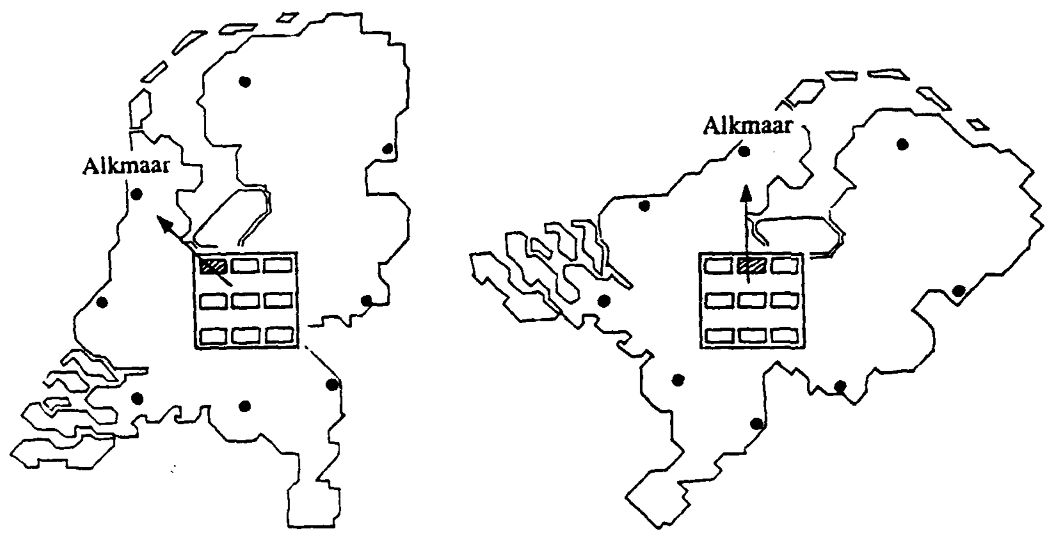

Fig. 5 Pointing as a check on mental orientation. The eight cities of the spatial task can be imagined in the North-up orientation (left panel) or in tilted orientations such as North-West up (right panel). Rotation of the map over the angle commanded by the stimulus is required for "pointing to" a city (Alkmaar in this example). This map is used for illustration only; subjects did not see the map during the task.

Trials were concatenated; the final line of sight of trial i was used as the initial line of sight of trial $i + 1$. Revisions of the imaginary orientation were thus required at presentation of the stimulus commanding mental rotation—not between consecutive trials.

6.4 Verbal-numerical test

The verbal-numerical test was the alphabet arithmetic task of Logan (1988) also contained in the ABC Battery of the British Armed Forces (Collins, Irvine, & Dann, 1990). The verbal-numerical test had the same format as the spatial orientation test as far as possible. The initial "line of sight" was a letter, specifying the initial location in the alphabet. Four and a half seconds later, and after a blinking warning signal, the "mental rotation" command was presented, a signed addend, specifying the number of steps in the alphabet to count forward or backward. The addend was 0, ± 1, ± 2, ± 3, and ± 4. Examples are A+2 (answer "C") and P-3 (answer "M"). The letter at the beginning of the next trial was the same as the final letter of the previous trial.

Subjects had to find the new location in the alphabet. Then, they pressed the central button of the 3 × 3 response panel. This immediately triggered the presentation of a 3 × 3 matrix. The matrix was displayed for 0.6 s. It contained a star surrounded by eight capital letters, one of which was the outcome of the alphabet counting. Subjects had to point to that letter by selecting the appropriate button of the 3 × 3 response panel. Incorrect selections triggered an error message. The next trial started 0.25 s after the letter identification response or 1.0 s later if a response error had been made.

6.5 Procedure

Trials were presented in blocks of 100. A performance summary appeared at the end, consisting of the average processing time and the number of trials correctly. This served to keep the subjects informed about their performance and to enhance their motivation. Subjects were instructed to respond as fast as possible while avoiding errors. In the blocks of the spatial orientation test, all 80 combinations of mental rotations (±0°, ±45°, ±90°, ±135°, and ±180°) and body rotations (±45°, ±90°, ±135°, and ±180°) were presented at least once and 20 randomly selected combinations were used a second time. The body rotation started at presentation of the mental-rotation stimulus. The pointing stimulus was a random choice out of the eight locations. In the blocks of the verbal-numerical test, all 80 combinations of addend (±0, ±1, ±2, ±3, and ±4) and body rotations (±45°, ±90°, ±135°, and ±180°) were presented at least once and 20 randomly selected combinations were used a second time. The body rotation started at presentation of the addend command. The position of the target letter in the 3 × 3 matrix was randomly selected.

Control blocks were the same as experimental blocks, except that the chair's motor was inactive.

Subjects came for two sessions on two separate days. The first day was for practice. The tests were introduced with blocks of 20, 50, and 100 trials per test, administered on a desk-top computer without facilities for body rotations. The experimental session took place 14 days later (between 6 and 21 days). The apparatus shown in Fig. 4 was used. A refresher block of 30 trials on each test under stationary conditions started the experimental day. Then, body rotations were demonstrated in a block of 10 trials. Subjects were instructed to ignore the body rotation. Data collection started subsequently.

For each test (spatial or verbal-numerical; S or V) one control block of 100 trials and two experimental blocks of 100 trials each were run. Breaks of at least 35 minutes were inserted between consecutive blocks. There were four combinations, defined by cognitive ability (S or V) and presence or absence of body rotation (P or A). All subjects did all four combinations SP, SA, VP, and VA. The presentation order of combinations was counterbalanced between subjects.

Half of the subjects did the spatial test before the verbal-numerical test in either SP-SA-VA-VP or SA-SP-VP-VA order. The other half of the subjects did the verbal-numerical test before the spatial test in either VP-VA-SA-SP or VA-VP-SP-SA order.

7 RESULTS

7.1 Drop-out subjects

One subject could not cope with the spatial orientation test. In the practice blocks, the error percentage was 78% and processing times were twice as long as those of other subjects. Halfway the second session, accuracy improved but still was unacceptable (68% errors) and processing times were increasing. The experimenter then terminated the session. The data of this subject were discarded. Another subject did not complete the experimental session because of motion-sickness complaints. Data of the remaining 36 subjects were used for analysis.

7.2 Motion-sickness complaints

Six out of 38 subjects reported one isolated and mild symptom possibly related to motion sickness. The complaint was dizziness for three subjects, headache for another, a strange feeling in the stomach for another, and nausea for still another. All symptoms were confined to one trial block only. The data of these subjects were retained. A seventh subject had multiple complaints: dizziness, headache, and nausea. This subject quit the experiment halfway. No symptoms were reported by the remaining 31 subjects (82%).

7.3 Data categorization and culling

Data were categorized factorial per subject (36), per cognitive test (2), per body-rotation condition (2), and per mental-rotation condition (spatial orientation test, 9) or value of the addend (verbal-numerical test, 9). Trials with extremes in either mental rotation time or pointing time (spatial test) or in either counting time or pointing time (verbal-numerical test) were discarded. The criterion was a processing time 1.5 times the standard deviation above the mean of either rotation/counting time or pointing time, with standard deviation and mean determined for each cell individually. This culling removed 21% of the data.

7.4 **Analyses**

Two analyses were run. In the first, cognitive performance was studied as a function of presence or absence of body rotations. In the second, cognitive performance in the body-rotation blocks was analyzed as a function of the amount of body rotation. Time to make the mental rotation (spatial test) or counting time (verbal-numerical test) was the dependent variable in both analyses. The conflict between the direction of mental rotation and body rotation was studied in a separate analysis on the spatial test. Parallel analyses using the same design were run on error proportions and pointing times.

The first analysis failed to reveal an effect of the presence as opposed to the absence of body rotation on the time for mental rotation or for alphabet counting [2.39 vs 2.34 s, respectively; $F(1,35) = 1.17$]. This finding held irrespective of the ability tested [$F(1,35) < 1$]. Similar results were observed for pointing times and errors. Pointing times and stationary and body-rotation conditions were 1.56 and 1.60 s [$F(1,35) = 1.38$] and there was no interaction with the ability tested [$F(1,35) < 1$]. Error percentages under stationary and body-rotation conditions were 2.7 and 3.1% [$F(1,35) = 1.04$] and again there was no interaction with the ability tested [$F(1,35) < 1$]. Note, however, that there was a consistent trend in all dependent variables toward worse performance in the conditions with body rotations.

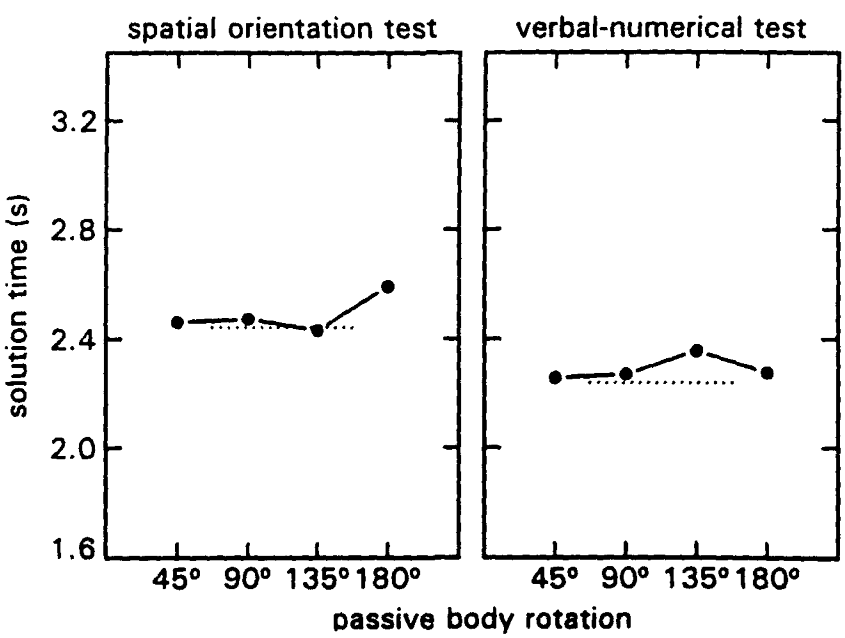

Fig. 6 Time to solve test items as a function of the amount of body rotation undergone passively on a rotating chair. Dotted lines indicate the control condition.

The more detailed analyses on the data of the body-rotation condition revealed that processing times for neither the spatial not the verbal-numerical task were increased if the body was rotated over an increasing distance [$F(3,105) = 2.05$; $p = 0.11$]. However, there was an interaction with the ability tested [$F(3,105) = 3.12$; $p < 0.05$]. Fig. 6 shows that this was due to the effect of body rotations at 135 and 180°. The time for a mental rotation increased at 180°, whereas the time for alphabet counting increased at 135° only. A separate analysis on the data of the spatial orientation task revealed a significant effect of amount of body rotation [$F(3,105) = 7.01$; $p < 0.01$]. Amount of body rotation had no effect on proportion errors or on pointing times [$F(3,105) = 1.56$ and 1.73, respectively]. No interaction was observed between amount of body rotation and type of ability in errors or pointing times [$F < 0$ and $F(3,105) = 1.41$, respectively].

Direction of body rotation (conflicting with the mental rotation or not) had an effect of marginal significance on mental rotation time [2.46 and 2.52 s, respectively; $F(1,35) = 3.16$; $p < 0.10$]. The effect should be considered as real because it replicates the finding of a previous experiment. Moreover, similar effects are reported elsewhere (Corballis & McLaren, 1982, see introduction). Direction of body rotation had no effect on errors (2.9 and 3.2%, respectively; $F < 1$) or on pointing times of the spatial orientation tests (2.15 and 2.14 s, respectively; $F < 1$).

8 DISCUSSION

The experiment revealed two small effects of passive body rotations on cognitive spatial ability. First, the time to solve the items of the spatial orientation test increased due to body rotations but only if the subjects were rotated over 180°. Second, conflict between the direction of the body rotation and the mental rotation also increased the time to solve the test items. These two findings support the conclusion of the previous studies—Body rotations reduce the capacity for information processing.

The *small effect size* of the two findings points out a theoretical problem. A well-known weakness of resource theory is that there is no guideline to decide when interference is enough to signal resource competition (see e.g., Kantowitz, 1987). Given enough statistical power interference is almost unavoidable. Based on the data of the current experiment in isolation, one could defend the position that passive body rotations and mental rotations do not use common resources—for all practical purposes, the interference is negligible.

The results indicate task specificity. Rotating the body over 180° had a negative effect on the spatial test whereas no effect was observed in the verbal-numerical test. This suggests a competition for specific spatial resources. Task specificity is

also evidenced by the effects of directional conflict between body and mental rotation because directional conflict is logically confined to spatial tasks. A reasonable explanation for the second finding—directional conflict—is crosstalk or outcome conflict (Navon, 1984, 1985; Wickens, 1989; Fracker & Wickens, 1989). Body rotation and spatial cognition have similar outcomes and there is some tendency to confuse the two.

In the next paragraphs, three issues will be addressed. The first is the smaller effect size of the present experiment compared with the effect size of the previous experiment. The second issue is the nature of the attention caught by body rotations. The third issue is the comparison between active and passive body rotations.

The first issue is the different effect size in the experiments on passive body rotations. The experiment described in the introduction revealed much stronger effects than the current experiment (compare Figs 2 and 6). Differences in the experimental method could have been the cause. Most prominent among the differences are the way the body rotated and the training schedule.

Concerning the way the body rotated, the rotations of the last experiment took less time and evoked accelerations twice as strong as those of the previous experiment. An explanation in terms of accelerations is, however, not very likely because it would predict *greater* effect size in the present experiment instead of the observed smaller effect size. At the same time, the observation of smaller effect size in the present experiment rules out an explanation in terms of vestibular-ocular reflexes[1].

An explanation in terms of the time the body was in motion seems more likely at first sight. All body rotations of the current experiment took 2.2 seconds, whereas those of the previous experiment took 1.5 to 5.0 s, depending on the amount of body rotation. The previous experiment thus had a confounding between amount and duration of rotation. There could have been a critical duration of, or a *threshold for attention capture* for, passive body rotation. Above-threshold body rotation would capture the subjects' attention, whereas below-threshold body rotation would be ignored. However, this explanation predicts an interaction with the duration of the cognitive process. The longer the cognitive process, the greater the probability of attention capture. The effects of body rotation should thus interact with any variable that affects the duration of the cognitive process, for example, the amount of mental rotation required. No interactions of this type were observed. This refutes an explanation in terms of the time needed for passive body rotations.

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[1] As pointed out in the introduction, a second reason to doubt an explanation in terms of accelerations (through vestibular-ocular reflexes) is that the maximum acceleration decreased with increasing angle of body rotation. This predicts decreasing effects with increasing amount of body rotation. Fig. 2 shows that the opposite was observed.

Another difference between the two experiments is the *training schedule*. The training session of the last experiment was without body rotations. Body rotations were added in the data-collection session only. In the previous experiment, by contrast, training and data-collection trials were administered under body-rotation conditions. In other words, the subjects of the previous experiment were practised under full-task conditions (ability test plus body rotations), whereas the current subjects were practised under partial-task conditions (ability test without body rotations). Van Rooij and Roessingh (19..), in their continuation of the learning strategies program (see Volume 71 of Acta Psychologica, e.g. Lintern, 1989) obtained evidence that test performance is more resistant to distraction if trained without distracter. That is, training subjects under full-task conditions will not render the same level of subsequent test performance as training subjects under part-task conditions (without distracter). This suggests that stable cognitive performance strategies develop faster under part-task conditions. These stable strategies protect cognitive processing against subsequent distraction. Passive body rotations are thus more distracting for subjects not yet having developed stable cognitive strategies. This predicts that passive body rotations are distracters only if subjects have had little practice. This can be tested in another experiment.

This raises the second issue for the present discussion: the nature of the attention caught by the body rotations. If capacities or resources can really be divided among tasks (e.g. Wickens, 1984) reductions in the *speed* of information processing and, hence, interactions between duration of the cognitive process and body rotation are predicted; for example, interactions between amount of mental rotation required and presence versus absence of body rotation. Such interactions are notably absent. For active body rotations, the data rather suggest a suspension of cognitive processing, a temporary standstill, rather than more or less continuous reductions of capacity. The interference is thus more bottleneck-like than pure resource theory assumes (see also Navon's discussion, 1984. 1985, or Tsang & Shaner, 1992). The resources are temporarily devoted to the body rotation task; then they are switched back to the mental rotation task. One could speculate that subjects follow this as a strategy in order to avoid outcome conflicts.

The last issue for discussion is the difference between active and passive body rotations. The expectation of stronger effects for body rotations made actively is duly confirmed. Active rotations constitute a task for the subject whereas passive rotations don't. An elegant explanation is that both types of body rotation bring cognitive processing to a temporary standstill, but that the duration of the suspension is much shorter if the rotations are undergone passively.

A final comment on the similarity with the visual field studies of Sanders is due. Sanders reports a pattern of cognitive suspension in experiments in which large eye movements were required for the cognitive task (Sanders & Houtmans, 1984, 1985; see also Boer & Van de Weijgert, 1991). There could be a common

explanation. In both the visual field studies and the body rotation experiments, the subjects shift their gaze toward a new location in space and are, hence, preparing for the intake of new information. It may be that the critical element causing suspension is the preparation for the intake of new information. In other words, not body rotations *per se*, but preparing for information intake is the reason why body rotations bring cognitive processing to a standstill. The reason why less problems are caused by passive body rotations is that the subjects don't prepare for seeing new information (Fig. 3; the display is rotated with the body). The idea can be tested in an experiment with several computer displays located around a rotating chair. The body rotation still is passive, but new information is actively searched for.

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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

A series of studies examining how whole-body rotation affects cognitive processing is summarized, and a new experiment is described. The main question was whether rotations of the body capture attention and reduce cognitive processing capacity. An additional question was whether the attention caught is resource specific, that is, whether particular cognitive capacities are more affected than others. Previous experiments revealed that cognitive processing comes to a complete standstill while body rotations are made actively on a swivel chair. The duration of the suspension depended on the nature of the cognitive task, suggesting resource specificity. In the present experiment a rotating chair was used on which subjects were rotated while performing on spatial and nonspatial tasks. Performance losses were small and limited to the spatial task. The conclusion based on the whole series of experiments is that body rotations capture general as well as specific processing capacity, but that the amount of capacity caught is small, or the duration of capacity capture is short. Large attention capture is expected only if subjects execute the rotations actively. The striking similarity with the effects of eye movements on cognitive processing suggests that the active search for new information in the visual environment is the real reason why whole-body rotation can be so disturbing.

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